AEI

Electrical Distribution

THE NEWS MAGAZINE OF THE CABLE AND CONSTRUCTION (CABLES & LINES) DIVISIONS OF ASSOCIATED ELECTRICAL INDUSTRIES LTD

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EDITORIAL

ADDRESSING THE Annual General Meeting of Associated Electrical Industries Limited, the Rt Hon. Viscount Chandos, chairman of the Company, covered the whole range of A.E.I. manufacture.

Lord Chandos's conviction that the success of A.E.I. is related to coverage of the whole electrical field is well known. The Company, employing more than 100 000 people who play their part in the manufacture of electrical equipment ranging from tiny transistors to huge turbine-generators, is in a good position to take advantage of future trends.

In 1960 the electrical and allied industries' share of this country's exports totalled £293 million and this represented 10% of the total exports of manufactured goods from the U.K. A.E.I. made a notable contribution to this figure.

The Construction (Cables and Lines) Division, many of whose contracts are featured in this journal, had a successful year. In the Cable Division, rationalization is practically complete, although it was a complicated task. The forthcoming year should prove that this internal reorganization will benefit both the Division and its customers in the electrical contracting and supply industries.

AEI

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OUR COVER PICTURE

An 11kV cable and a 33kV cable have been laid across the River Bann in Northern Ireland by A.E.I. Construction Division for the E.B.N.I. A compressed-air technique was used to install the cables 4ft 6in. deep in the bed of the river. Story on page 99.

News in brief...

N.I.C.E.I.C. Appointments

N.I.C.E.I.C. chairman Mr S. E. Goodall.

Vice-chairman Mr J. D. D. Shaw.

Mr S. E. Goodall, M.SC.(ENG.), M.I.E.E., director of engineering on the board of Associated Electrical Industries (Woolwich) Ltd, has been elected chairman of the National Inspection Council for Electrical Installation Contracting.

Mr Goodall, who joined W. T. Henley's Telegraph Works Co. Ltd in 1944, became chief engineer of the Company and was later appointed to the board. He was chairman of the I.E.E. Supply Section 1950–1 and has served on many I.E.E. committees, including the Wiring Regulations committee, of which he is vice-chairman. He was president of the I.E.E. in 1959. Mr Goodall became a member of the board of A.E.I. (Woolwich) Ltd in 1960.

Mr J. D. D. Shaw, M.B.E., managing director, James Kilpatrick and Son Ltd, has been appointed deputy chairman of the N.I.C.E.I.C. Mr Shaw is a member of the Scottish committee of the National Inspection Council. He has been a member of the National Inspection Board since the Council was incorporated in 1956. Other appointments he has held include the past-presidency of the Electrical Contractors' Association of Scotland and of the Paisley Association of Electrical Engineers.

Extension to Worthing Grid

A £65 000 CONTRACT has commenced at Worthing, where the yellow-and-black drums of A.E.I. cables can be seen at Worthing Grid substation. The contract is being carried out by the A.E.I. Construction (Cables and Lines) Division for the South Eastern Electricity Board to connect the Grid substation to a new substation situated at North Worthing.

A run of two 0·20sq.in. 33kV 3-core oil-filled cables will be laid along a 2¼-mile route through the Worthing suburbs to carry power to meet the rapidly increasing load in the Worthing district. Accompanying the feeders will be a 7/0·029in. 6-core plus 1/0·044in. 8-pair pilot and telephone cable which will provide the necessary intertripping and link the new substation to the South Eastern Board's private telephone system at Worthing Grid substation.

A small amount of 11kV cabling at Worthing North is also included in the work.

Unpainted Steel Overhead Structures

A NEWS ITEM from North America should arouse interest in view of the recent C.E.G.B. experiments in tower camouflage.

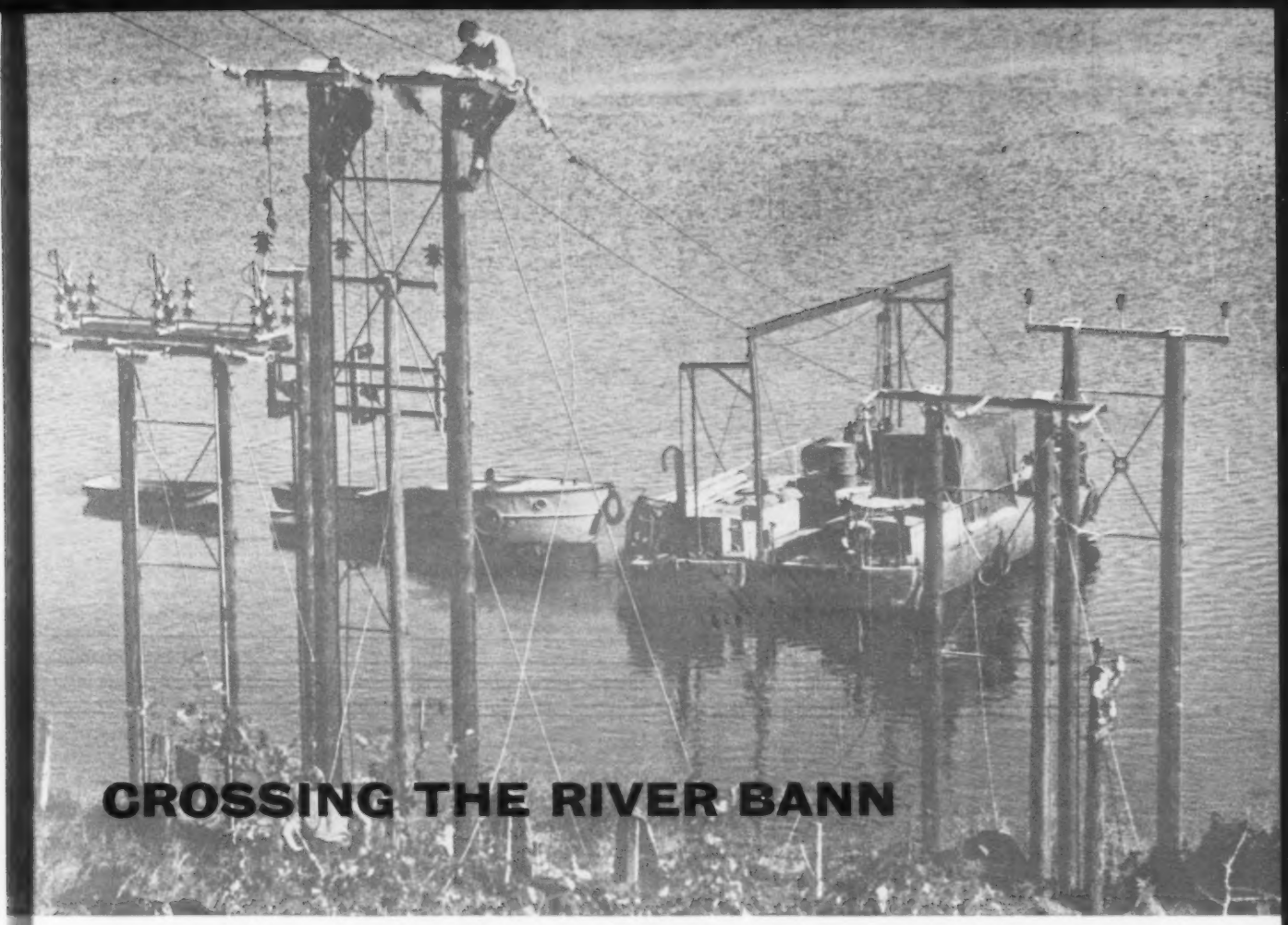
This is the use of an uncoated steel transmission tower in Project EHV—the 650kV experimental power system being erected by the General Electric Company of America near Pittsfield. Tower No. 18 on the system will be built of unpainted, uncoated Cor-Ten steel, a product of the United States Steel Corporation.

Cor-Ten is a high-strength, low-alloy steel with more than four times the atmospheric corrosion resistance of carbon steel. Instead of the flake rust which eats away plain carbon steel, a non-porous oxide layer forms on Cor-Ten during its first twelve to eighteen months' exposure to the atmosphere. The layer is non-flaking, a chocolate brown in colour, and it provides, in effect, a protective coating against further atmospheric corrosion.

All structural members and bolts and nuts on Tower No. 18 will be made of Cor-Ten. The tower will act as a test piece towards future savings in tower maintenance.

Indian Journal's First Decade

CONGRATULATIONS ARE DUE to the *Indian Electrical Contractor and Trader* which this year celebrates its tenth year of publication. Its souvenir issue carried the theme "India can make it", which has been the journal's slogan since its inception—a slogan which has proved more and more apposite as India has developed her resources and heavier industries under consecutive Five-year Plans. Electrification of the country is of first importance and India has rapidly expanded her supply network and her production facilities for electrical equipment. The *Indian Electrical Contractor and Trader* has reflected this progress in its pages during the ten years of its existence. It will certainly have even greater future progress to report.



CROSSING THE RIVER BANN

Compressed-air technique used to bed down cables in Northern Ireland submarine cable crossing

AN INTERESTING JOB has just been completed by the A.E.I. Construction Division for the Electricity Board for Northern Ireland in connection with a cable link across the River Bann for two new overhead lines erected by the Board.

The overhead lines themselves comprise a 33kV ring main around Coleraine Town and an 11kV distribution system. Both lines terminate on either side of the tidal River Bann on H-pole anchor structures at a site near Coleraine, five miles from the river mouth.

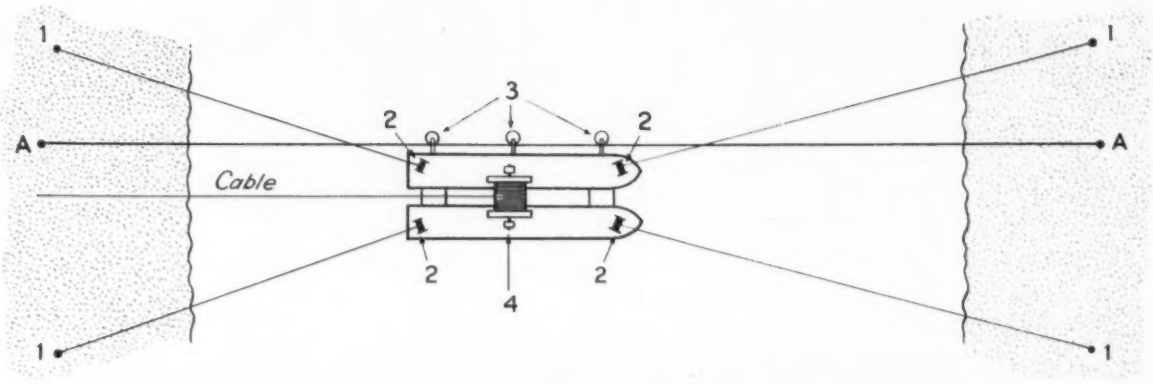
The River Bann is approximately 540ft wide at high-water at this point, and is constantly traversed by shipping wishing to reach the inland port of Coleraine. Consequently, to avoid the use of high steel towers, two submarine cables were required to establish a link for each line across the river.

River conditions

Preliminary investigation revealed that the river bed was primarily composed of sand, gravel, and silt. The profile of the bed was such as to preclude normal methods of dredging the trenches, and the scouring action of the tides would, in any case, have filled in the excavations and caused difficulty during the subsequent laying of the cables. Supplementing the excavation problems were the additional problems of a four-knot current in the river, which precluded a method of winching the cables across on floating drums, and the marshiness of the river banks.

It was therefore decided to excavate separate trenches for each cable using a method previously proved successful by A.E.I. engineers when they had installed a submarine cable across Larne Lough for the E.B.N.I. This involved the use of hydraulic/pneumatic equipment devised by Messrs Kitson, engineers, of Larne, mounted on a special rigging barge of twin-hull construction.

Using this equipment, it is first necessary to lay the cables on the bed of the river, before any excavation is commenced. The barge is so constructed that a drum of cable can be mounted amidships for the initial laying, so utilizing the same vessel throughout the operations.



A–A = Guide-wire 1 = Winch wire anchors 2 = Winches 3 = Snatch blocks 4 = Drum jacks

▲ **Sketch showing the method used to control the barge during excavation of trench in the bed of the River Bann.**

▼ **Loading a cable drum at Coleraine harbour.**

This illustration shows many details of the twin-hull barge used in the operation: extreme right is one of the four hand winches; next to it is one of the anchoring tubes—its twin rises from behind the cable drum; the light-coloured pipe, forked at its lower end, is the scouring gear which runs along the R.S.J. at the top.

Conditions on the river made it essential to choose a time of slack water and absence of shipping, giving the crew a period of sixty minutes to complete the laying of each cable. In the event, each cable was laid accurately across the river in forty-five minutes. Control of the special barge during this and the subsequent trenching work was managed by hand. The diagram opposite shows the arrangement used.

The vessel

Four hand-driven winches are mounted bow and stern on the twin hulls, and the winch wires are anchored securely on firm ground ashore. As a further aid to maintaining a straight course, a taught guide wire is used, also anchored ashore, running through snatch blocks fitted to the side of the barge.

The equipment on the barge is worth mentioning in some detail. The jetting apparatus consists of a vertical arm combining water-jet and compressed-air nozzles which are split into an inverted U at the lower end. The inverted U section, guided by a diver, is lowered over the cable on the river bed through an open well between the hulls. The cable is contained between the arms of the U and, as the water jets scour out an excavation, the spoil is blown up through a large-diameter pipe to be ejected over the side of the barge while the cable settles into the trench thus formed. The depth of the trench can be controlled by means of the chain blocks from which the jet arm is suspended.

The chain blocks run along a 25ft R.S.J., carrying the scouring gear along the length of the barge, so that a 25ft length of trench can be excavated while the barge is anchored in one position. Secure anchoring is achieved by means of two 30ft stout steel tubes which are lowered through openings fore and aft in one of the twin hulls of the barge and set firmly into the river bed. The jetting apparatus can then scour out 25ft of trench, the cable is bagged with concrete-filled sacks by divers, and the anchor legs are lifted to enable the barge to be winched forward another 25ft and anchored once again, ready for further scouring.

The depth of the trenches across the river was set at 4ft 6in. Scouring and bagging proceeded at the rate of 75ft each day, and when a day's work was finished the barge was left in position with the anchor legs down in addition to normal anchors, the winch wires being lowered to the river bed. Winch wires were also lowered during operations, when shipping had to be allowed to pass. The main shipping channel is close to the west side of the river and scouring across this was carried out on days when no shipping was expected. Trenching near the banks was done by hand at low tide.

The maximum depth of the River Bann at the point of crossing is about 14ft. It says much for the efficiency of the jet-and-lay method that the crossing, requiring a considerable depth of trench, was completed so quickly and without trouble under the conditions existing on the river.

Cables

Both cables installed across the Bann were manufactured at the A.E.I. Cable Division's Woolwich works, shipped to Belfast, and transported to Coleraine harbour by road, where they were transferred to the barge by crane. At high tide the barge was towed downstream to the site of the crossing.

The 33kV cable is a 0·15sq.in. 3-core screened, individual cores lead sheathed (i.e. an HSL type) paper-insulated, lead sheathed, double wire armoured and served cable. It was manufactured for submarine installation with a thicker lead sheath than is normally specified for cables to B.S.480/5, was armoured with 0·16in. armour wires, and finished with two coats of heavy three-ply jute overall. The cable was terminated in 33kV outdoor type sealing ends on a switch H-pole after the cores had been separated by means of a pole-mounted splitter box.

The 11kV cable is a paper-insulated lead sheathed 3-core belted type, and this cable also had a thicker lead sheath for underwater installation. Its double wire armour protection was formed of 0·128in. wires and jute finish was applied similar to that on the 33kV cable. It was made-off in a terminating box on the 11kV switch H-pole.

Supporting steelwork on the poles was provided by A.E.I. and all terminations to the pole-mounted equipment were carried out by A.E.I. jointers.

The photographs illustrating this article and the photograph reproduced on the cover of this issue of ELECTRICAL DISTRIBUTION were taken by Mr J. Savage, of the Electricity Board for Northern Ireland, Coleraine. They appear by his kind permission.

New Literature

Two new folders are available describing Cable Division products.

Folder 30M/2/61—Heat control in a plug—REGUPLUG

The folder describes the Reguplug, the 3-pin plug with the built-in Simmerstat. This useful electrical accessory gives fully variable control for most electrical heating appliances and is available in 13A and 15A types.

Folder CD. 202—Microphone Cables

A.E.I. microphone cables to accepted standards as agreed between the C.M.A., the British Radio Equipment Manufacturers' Association, and the Radio and Electronic Component Manufacturers' Federation. The folder gives details of types, specifications, and reference numbers.

These folders are obtainable upon request from A.E.I. Cable Division district offices and branches or direct from Associated Electrical Industries Ltd, Publicity Department, Crown House, Aldwych, W.C.2.

New Lightning Flashover Theory Proposed*

New explanation of lightning flashover may indicate why transmission line performance has not met design standards

by S. B. GRISCOM, Advisory Engineer, Electric Utility Engineering Dept., Westinghouse Electric Corp., East Pittsburgh, Pa.

THE 60CYCLE POWER voltage is sufficient to cause transmission line flashover in cases where lightning has reduced the electric strength of the air in the vicinity of the towers. Briefly, this type of flashover is produced by induced voltage, and not caused by a direct stroke to either the tower or the phase conductor. A theory only, this type of flashover could explain the failure of some transmission lines to meet expected design standards.

Transmission line flashovers from lightning are generally regarded to be the result of one or the other of two basic mechanisms, or modes:

Mode 1: The lightning stroke terminates on the steel tower or ground wire. The tower-top potential then rises with respect to that of the power conductors because of tower-footing resistance, inductive drop in the tower, and the electric field changes associated with the stroke. If there is a sufficiently great difference of potential, a flashover occurs. Such flashovers are also called "backflashes".

Mode 2: The lightning stroke terminates on a power conductor, raising it in potential with respect to the tower. Flashover is practically certain, and such flashovers have been termed "side-flashes" or "shielding failures". These are usually ascribed to failures of the ground wire system to shield the power conductors.

By following the construction principles laid down about thirty years ago, with regard to shielding with overhead ground wires and getting low tower-footing resistances, transmission line tripouts from lightning have been reduced to a rate of the order of 1/30 of that which prevailed before the direct stroke theory. Thus, the essential soundness of Modes 1 and 2 is well established and accepted by the industry.

Despite this excellent record, there are many instances of poor performance where line designs met the requirements for minimizing Mode 1 and 2 flashovers. Such examples indicate the possibilities that the available data on lightning stroke characteristics are inadequate, performance calculation methods need improvement, and possibly that there are other flashover modes.

Mode 3: Prestrike theory predicted that the lightning stroke current wave-form was more complicated than had been previously considered. Under it, high tower-top potentials might occur, even with perfect shielding and low tower-footing resistance. This is a Mode 1 or backflash type of flashover. But since it is caused by a different set of circumstances, and is improvable by different means, it will here be called a Mode 3 flashover.

Field tests are being conducted with kine-klydonographs by the American Electric Power Co., Commonwealth Edison Co., Ohio Edison Co., and West Penn

* Reprinted from *Electrical World*, 20 March 1961. Copyright 1961, McGraw-Hill Publishing Company.

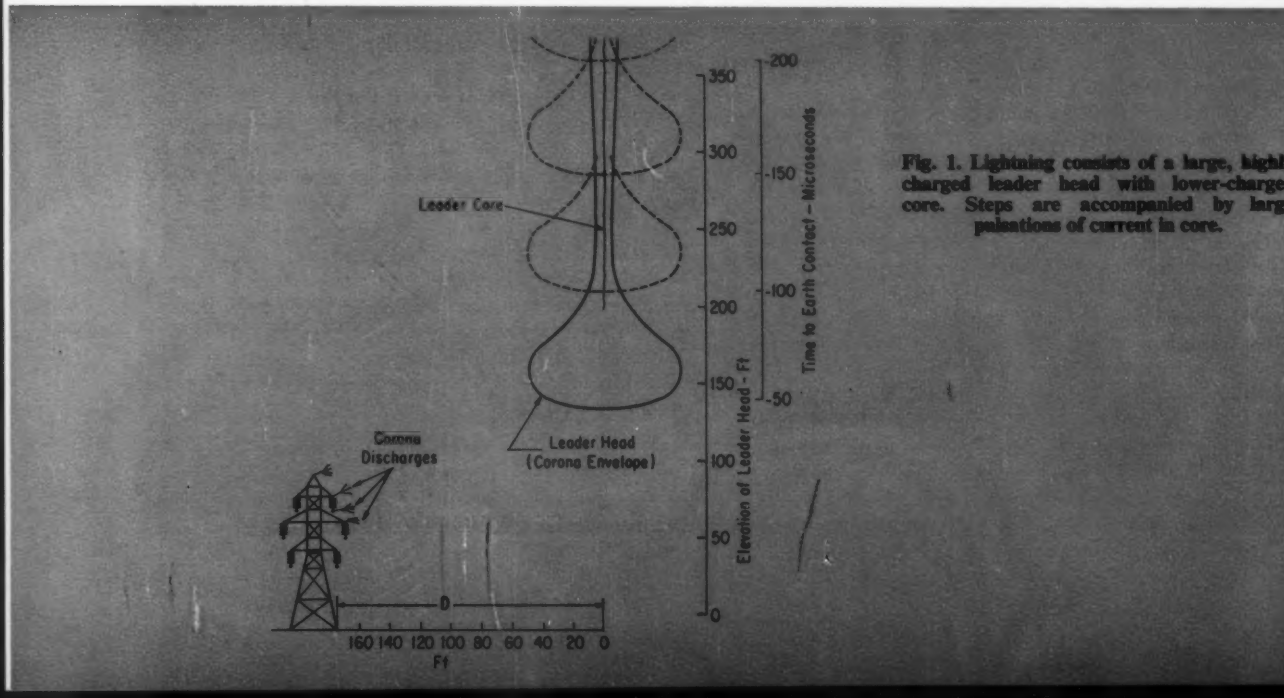


Fig. 1. Lightning consists of a large, highly charged leader head with lower-charged core. Steps are accompanied by large pulsations of current in core.

Power Co., jointly with Westinghouse Electric Corp., to get data on the rise time of lightning stroke currents. So far, only three records have been obtained during this programme. This is an insufficient number for statistical evaluation.

The work of Schonland, about twenty-five years ago, showed that a lightning stroke is initiated by a downward "leader stroke" which proceeds by steps about 75ft long and has pause times of about 50microseconds. This work also considered that the cross-section of the leader was fairly uniform along its length including its tip, the current flow was relatively steady, and that charge was lowered at a uniform rate, despite the steps observed photographically.

Prestrike theory, on the other hand, predicted that the tip or head of the initial leader was physically large, contained a much higher charge per unit length than the rest of the leader, and the steps were accompanied by large pulsations of current in the leader core. The events just prior to contact between the leader head and ground according to the prestrike theory are shown in Fig. 1, alongside a 100ft tower for comparison. Diameters of the envelopes of charged ions about the leader channel and leader head are shown according to their calculated relative diameters. Both envelopes are more or less figures of revolution about a small, about $\frac{1}{8}$in.-dia., highly ionized leader core.

Significance of a large leader head lies in the high electric field intensities produced at locations up to several hundred feet distant. In Fig. 2, A is a plot of the calculated field intensity at 100ft elevation against lateral displacement from a leader head poised at 150ft elevation as in Fig. 1, and charged to 50 million volts. The field intensity is that which would exist in the absence of any conducting grounded objects, such as towers and power line conductors. When such objects are present, electric fields in their vicinity are greatly distorted and intensified. This is particularly so if the tower is high, and especially true with respect to the tips of crossarms where the insulators are attached.

Computation of the electric field intensification about a tower and transmission line is exceedingly complex and time-consuming. Fortunately, such calculations are not necessary, because if corona discharges occur, clouds of space charge, ionized air, will surround the crossarm tip, and intercept the electric field force lines from the leader head.

An approximate relation, available for determining the radius of such corona discharges, gives the results which are plotted as B in Fig. 2. It will be observed that the corona discharges will be quite long if the stroke is close to the tower, being more than commensurate with the length of an insulator string.

Actually, the electric field intensities are so large for distances under about 80ft, the corona discharges are expected to consolidate in a leader spark type of discharge, and continue to lengthen. This zone is roughly bounded by the dashed line a-b. The practical significance of this line is that a leader headed for ground would be attracted to the leader from the tower, and would make the necessary sharp change in direction.

Mode 4: With the points of view brought out by Figs. 1 and 2, the fourth mode may now be stated: A nearby downward leader, with a highly charged leader head, draws corona discharges from the crossarm tips, insulator string, and power conductor, reducing the electrical strength of the air in those zones. The 60cycle power voltage is then sufficient to cause flashover. In short, Mode 4 flashover is induced, and not caused by contact of the stroke with either the tower or the phase conductor.

At the present time Mode 4 is a theory only. Consideration of its possibility could lead to discovery by close examination of the terrain within a 300ft radius, when flashovers have occurred, but where magnetic link or other data indicate that no direct contact took place.

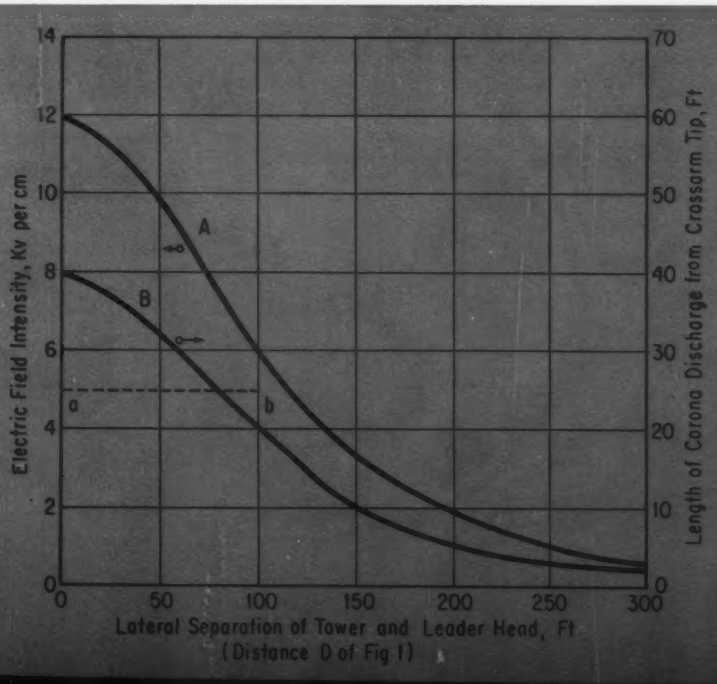


Fig. 2. Electric field intensity A around tower head increases as head nears tower, causing tower corona discharges B, longer than the insulator string.

High-speed and Slow-speed Auto-reclosing in Power Systems

by **A. SALZMANN**, Dipl.Ing., A.M.I.E.E.

Introduction

High- and slow-speed automatic reclosing of circuit-breakers has found increased application in recent years, particularly in power systems with solidly earthed neutral. Even in resonant neutral-earthed systems, auto-reclosing is employed to clear arcing faults between phases. In networks where no arcing faults are experienced, such as underground cables systems, auto-reclosing is not applicable, but for overhead lines (O.H.L.) automatically operated reclosing switchgear is desirable because the majority of the faults are transitory. In fact, most faults are non-persistent if the faulty network is disconnected at high speed. On O.H.L. there is a variety of faults caused by conductors swinging together, windborne material such as straw, hay, small branches of trees blown into the lines, gales, lightning, birds, kite strings which foul conductors and cause short circuits when rain is present, build up of ice and snow on conductors, mechanical failure of binder wires due to corrosion, etc. The main objects of auto-reclosing are therefore to: (a) remove arcing faults; (b) reduce damage to equipment; (c) prevent the spread of a fault to other phases, and (d) reduce the danger of an interruption of the electricity supply to consumers.

For successful reclosing on transient faults the operation sequence is "high-speed trip—reclose", while for unsuccessful reclosing, the fault being persistent, the sequence of operation is "high-speed trip—reclose—delayed trip—lockout". Thus the second, or final, trip on the recloser takes place during a period allocated by protective relays whose settings are based on discriminative fault clearance.

This is illustrated in the basic time-travel diagram, Fig. 1. Successful automatic reclosing is achieved if the faulty line is disconnected for a period called "dead time" or "AR-interval", sufficiently long for the transient fault to disappear, and to reconnect at the instant when the arc path has become de-ionized. Duration of the AR-interval should take into account the magnitude of voltage and arc current, design of the circuit-breaker, configuration of the network, and the nature of the load. In fact, duration of the AR-interval should distinguish high-speed auto-reclosing (HSAR) from slow-speed auto-reclosing (SSAR).

For HSAR a short AR-interval, say 0·2 to 0·3 second, is selected, particularly if the load consists mainly of asynchronous motors where the latter are equipped with under-voltage relays and should not stop during the period of the AR-interval. Here high-speed fault clearance, namely high-speed operation of the protective relay plus short break time of the circuit-breaker, is essential, because the longer the fault is permitted to continue the greater are the chances of further damage to the transmission elements and the worse is the deterioration of the dielectric strength across the fault path. Such conditions will call for longer dead time to clear the ionization effect in the fault path, if reclosing is to be successful.

In fact, high-speed reclosing of circuit-breakers employed in connection with fast relay protection and high-speed fault clearance has a better chance to be successful. Here reclosing is achieved if the circuit-breaker remains open just long enough for the recovery of the dielectric strength of the fault path but not long enough to interrupt the connected load.

It follows that successful auto-reclosing is a function of the AR-interval. The minimum duration of the dead time for rapid reclosing will depend mainly on the type and design of the circuit-breaker, while the maximum duration of the AR-interval is to be related to the nature of the load and network configuration.

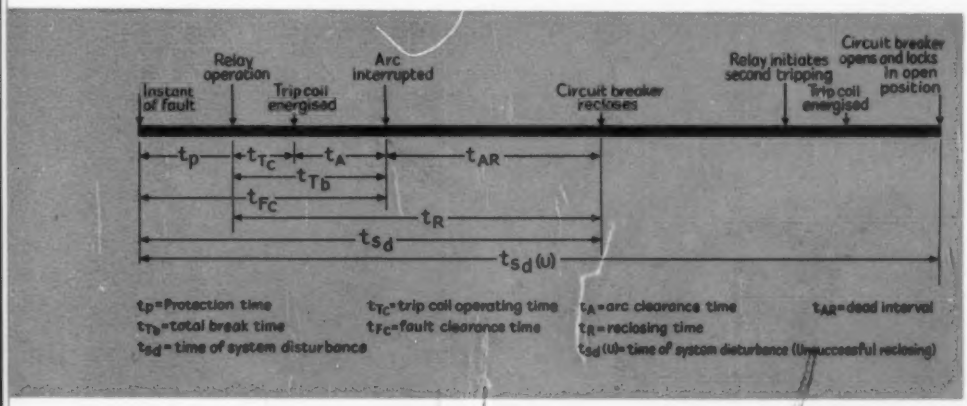


Fig. 1. Auto-reclosing cycle of a circuit-breaker.

Dealing with the minimum AR-interval for oil circuit-breakers, the period of interruption is longer (by reason of the arc-maintaining property of the extinguishing medium) than for air-blast breakers with no mechanical linkage and a de-ionizing air supply derived from an external source. Too *short* an AR-interval may result in unsuccessful reclosure, because if it does not allow time for the recovery of the dielectric strength of the fault path, namely at the instant of reconnecting the circuit, the voltage may restore the fault. Concerning breaker design, the requirements for an oil circuit-breaker are: (a) a small break time, i.e. trip-coil operating time, plus arc-clearance time, i.e. the time between relay initiating tripping and the instant the fault current ceases to flow; (b) a built-in automatically operating reclosing device giving a minimum AR-interval with a reclosing action initiated by an auxiliary switch operated by the breaker shaft; (c) a reclosing action initiated externally by a time-delayed reclosing relay, giving a controlled AR-interval, and (d) an operating mechanism which regains stability before the breaker attempts to reclose.

Regarding the maximum duration of the AR-interval for rapid reclosing, the latter should be related to the network configuration and nature of the connected load. During the dead time, the power failure should remain unnoticeable to consumers, while on return of power it should have no appreciable influence on the quality of the work performed by induction motor-driven machines. Usually, asynchronous motors should be equipped with under-voltage relays and power failure up to one second should have no appreciable effect on motor speed. However, when a voltage dip occurs, slight reduction of motor speed is possible which may result in a defect in the completed product; consequently, scrapping of the impaired material is unavoidable.

Synchronous motors on the other hand should drop out in about 0·3sec. It follows that the AR-interval should be long enough to maintain induction motors in circuit but short enough to permit synchronous motors to trip because, on return of power, synchronism may be lost. On systems where the load consists of large capacitors, large induction motors, and large synchronous motors, the stored energy may be sufficient to prolong the period of arcing; therefore it will be necessary to increase the AR-interval or, alternatively, to abandon auto-reclosing.

Finally, for interconnected power systems the AR-interval must be still shorter in order to prevent the networks falling out of synchronism at the instant of reclosing. Here the dead time is related mainly to system stability. An AR-interval exceeding the permissible value may result in loss of synchronism and hence complete shut down of either or several power stations. However, if single-pole reclosing instead of 3-pole reclosing is applied, a larger AR-interval is tolerable.

1. Slow-speed auto-reclosing (SSAR)

For SSAR a prolonged AR-interval is selected, from a few to several seconds, to enable the fault current to disappear. For tail-end feeders power failures are noticeable by consumers—street lighting (mercury vapour lamps) will fade out, lighting (filament lamps) will be affected, and induction motors will stop. Possibly, after reconnection, no diversity between some types of load will exist, which may result in trip-out of feeders on overload. Where the load consists mainly of lighting, momentary power failure can be tolerated and delayed reclosing is likely to have a better chance of being successful than high-speed reclosing.

In general, slow-speed auto-reclosing is disadvantageous for consumers supplied via tail-end feeders because of interruption of supply, but it is economically advantageous if the system is fed via ring mains and mesh-interconnected circuits. Here the existing slow-speed circuit-breakers and protective relays can be retained. At the occurrence of a fault more time for de-ionizing the fault path and reconnection is available due to the alternative supply to consumers. In this case, successful reclosure is ensured with slow-speed protective gear. The main object of employing auto-reclosers, even for networks with duplicated supply, is to prevent overloading of healthy feeders in the event of a fault and to reduce thermal stress in the system.

As an illustration, let us consider the circuits shown in Fig. 2, assuming impedance protection is applied to various feeder sections. On the networks shown in Figs. 2b, 2c, 2d, and 2e, we employ high-speed auto-reclosing

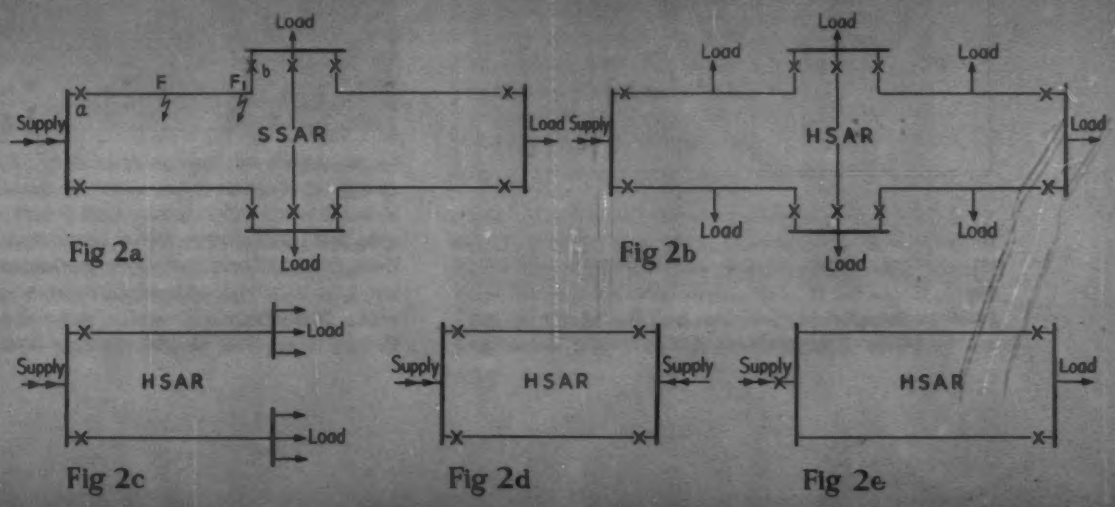


Fig. 2. Schematic single-line diagram for automatic circuit-breaker as applied to ring mains, mesh-connected networks, and tail-end feeders.

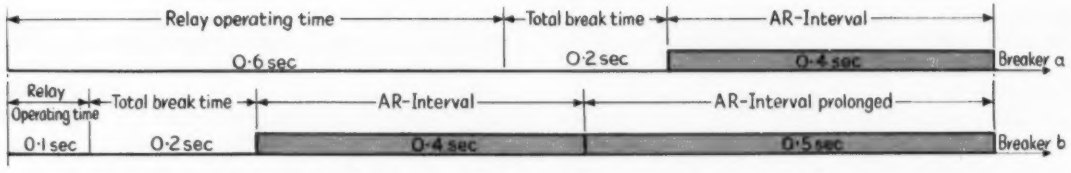


Fig. 3. Auto-reclosing cycles for two circuit-breakers with identical characteristics for circuit Fig. 2a.

(HSAR) to restore the supply as quickly as possible in the event of a fault. Comparing Fig. 2a with 2b, HSAR is required for the circuit Fig. 2b because of the tapped-off load from the transmission sections. On the other hand, for the network Fig. 2a slow-speed auto-reclosing is applicable because no supply via tapped-off load is involved. For a fault at location F_1 breakers *a* and *b* will not trip simultaneously because the fault is seen by the near-end relay *b* in its first zone (operating time 0·1sec) and by the far-end relay *a* in its second zone (operating time, say, 0·6sec). Here we have to lengthen the AR-interval of breaker *b*, since the near-end relay is ahead of relay *a* and the additional time must be added to the reclosing cycle, as shown in Fig. 3. It is very important to check the resultant AR-interval, as the arc should not restrike subsequent to reclosure. This will be accomplished if the faulty section remains disconnected at both ends long enough for the recovery of the dielectric strength of the fault path. Assume AR-interval =0·4sec and as an illustration let us check the resultant AR-interval for breakers *a* and *b* shown in Fig. 2a and assume circuit-breakers with identical characteristics. The time may be determined as follows:

Gear (b) Time sec	*Gear (a) Time sec*	*Operation*
0	0	Fault occurs
0·1	0·1	Near-end relay *b* operates and energizes trip-coil, while far-end relay *a* requires more time for initiating tripping.
0·3	0·3	Breaker *b* trips (total break time 0·2 sec) while relay *a* still has not initiated tripping.
0·7	0·7	Breaker *b* terminates its reclosing (AR-interval 0·4sec) at the instant circuit-breaker *a* starts to open its circuit.

It follows that in order to prevent unsuccessful auto-reclosing, the AR-interval for breaker *b* has to be increased from 0·4sec to 0·4+0·5=0·9sec, as shown in Fig. 3. Hence the total system disturbance time for relay *b* is 0·1+0·2+0·4+0·5=1·2sec and for relay *a* 0·6+0·2+0·4=1·2sec. The resultant AR-interval is 0·4sec and the faulty section remains disconnected at both ends for this period, long enough to de-ionize the fault path. For a fault F (Fig. 2a) and cleared by both relays simultaneously (0·1sec), the total system disturbance time for relay *a* is 0·1+0·2+0·4=0·7sec and for relay *b* 0·1+0·2+0·4+0·5=1·2sec.

2. High-speed auto-reclosing (HSAR)

2.1. Radical networks

For tail-end feeders the protective gear should comprise instantaneous elements set to operate before any slow-acting fuse to prevent unnecessary blowing of fuses, and time-delay devices set to avoid undesirable tripping under transient and overload conditions. Here we have two types of AR breakers, namely (a) pole-mounted reclosers with self-contained high-speed tripping and reclosing characteristics and high-speed circuit clearance; (b) ground-based reclosers with reclosing elements controlled either automatically by gear mechanically coupled to the circuit-breaker mechanism, or externally by a reclosing relay through an electric link.

2.1.1. Pole-mounted reclosers[1,2]

This gear employed in conjunction with slow-acting fuses is usually given an operating cycle of two instantaneous openings followed by two time-delayed openings before locking the breaker in open position. The

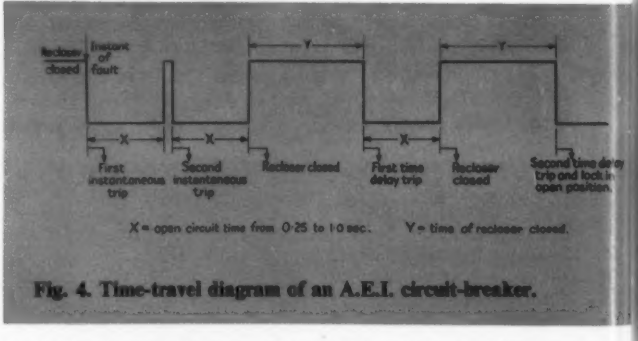


Fig. 4. Time-travel diagram of an A.E.I. circuit-breaker.

basic time-travel diagram of an A.E.I. recloser is shown in Fig. 4. Applied to the network shown in Fig. 5, recloser R removes the arcing fault F before the fuse operates, and remains open for about one second. During this time, the fault path de-ionizes, and should the fault persist a second high-speed interruption and reclosure is made. If the fault still persists, delayed opening and reclosure is applied, to give the fuse time to operate. A

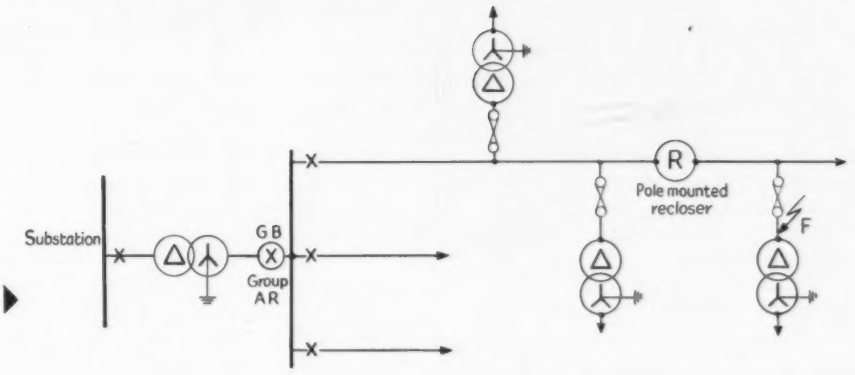


Fig. 5. Schematic diagram of auto-recloser as applied to tail-end feeders.

second delayed opening and reclosure is made if the fault remains of permanent nature, but if the fuse has not then operated (small fault current), the recloser will be locked in open position.

For further operation the circuit-breaker mechanism must be reset manually. However, if the recloser trips and the fault disappears before completing the sequence of operation, the former resets itself automatically after tripping and is ready for further operation. As a rule, three single-phase units form a 3-phase recloser. Should one unit complete its operational sequence and remain locked in open position—say in the event of a single-phase fault—the other units become automatically locked open as well, by means of a mechanical inter-coupling.

Generally, it is aimed to obtain correct discrimination between substation protective devices, reclosers, and slow-acting fuses, as shown in Fig. 6. It can be seen that the upper and lower limits of the co-ordination range between recloser and fuse are given by the intersection of the fuse curve and recloser characteristics, while discrimination between substation breaker and recloser is secured by adjustment of the relay settings accordingly. Selective operation is to be expected if the back-up relay is set to give about twice the delayed trip time of the recloser, but for sensitive earth-fault protection difficulties might be experienced.

However, if h-v fuses are not incorporated in the network, time-delayed trips of the recloser will not be required. Here the recloser mechanism can be modified, making all operations instantaneous, and, subsequent to the last trip, the breaker is locked in open position. The object of all instantaneous operations is: (a) to improve discrimination with the substation back-up relay, and (b) to provide discrimination between reclosers connected in series. In the event of a persistent fault, the breaker at the remote end, having, say, two instantaneous operations, will remove the faulty section from the network after two trips and reclosures, while the recloser at the near end of the tail-end feeder, which is provided, say, with three instantaneous trips, will maintain continuity of supply to the sound sections of the network after two trips and two reclosures.

Finally, it should be emphasized that circuit reclosers are faster than conventional ground-based circuit-breakers because series coil operation is utilized. The latter provides high-speed tripping and reclosing at the same time. The breaking capacity of the recloser is limited because of the thermal capacity of the series coil. Usually, the minimum tripping current is about twice the rated current. Reclosers with short-circuit rating over 75MVA are not yet available. Possibly the latter could be increased by deleting time-delayed operations and making all operations instantaneous.

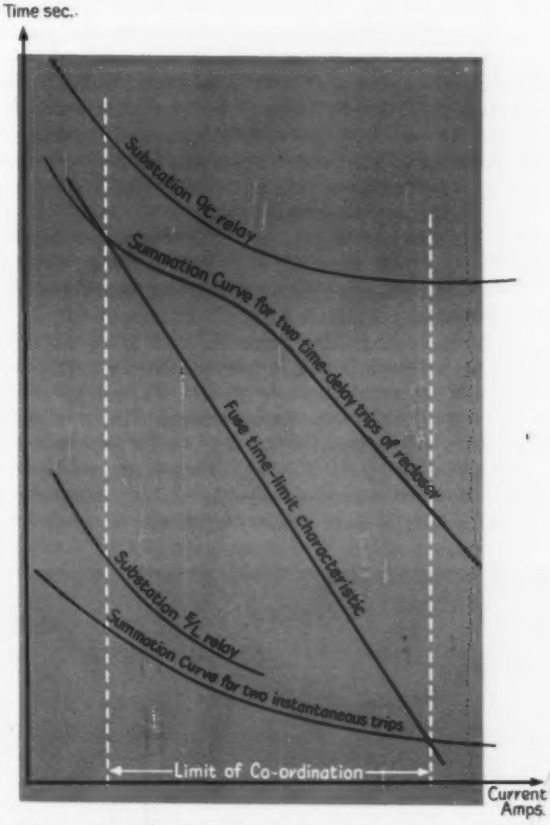


Fig. 6. Co-ordination curves of a pole-mounted recloser with fuses and substation protective relays.

2.1.2. Ground-based reclosers[3]

For radial networks the apparatus controlling auto-reclosing is less complicated since, in the event of a fault, only one circuit-breaker is involved. For tail-end feeders the breakers can be divided into three broad groups: (a) reclosers utilized for several substations connected in cascade (see Fig. 7); (b) common auto-recloser for radial feeders (see Fig. 5), and (c) employment of circuit-breakers for tail-end feeders, each of them having auto-reclosing features.

In the first group, high-speed overlap impedance protection is applied to the total length of each section. The instantaneous zones are extended into the adjacent sections—that is they are set to lap 120% of the corresponding feeder length, as shown by broken lines in Fig. 7. For a transient fault F, breakers *c* and *b* will trip and reclose simultaneously. If the fault is persistent, breaker *c* will trip again and will be locked in open position, while circuit-breaker *b* remains closed and maintains supply to substation III. This is achieved by a reclosing relay operating at the instant breaker *b* recloses and moving back the ohmic zone setting of relay *b* from 120% to 80% of the section length l_2. In this manner we have re-established discriminative fault clearance at the occurrence of a persistent fault. Overlap impedance protection has the advantage of rapidly clearing arcing faults along the total feeder length.

The second group of ground-based reclosers is usually employed in rural networks. As shown in Fig. 5, the group circuit-breaker GB is provided with auto-reclosing features, while the tail-end feeders are equipped with non-auto-reclosing circuit-breakers. For a transient fault on any feeder the sequence of operation is "high-speed trip—reclose", while for a persistent fault the group recloser remains closed for a further period to permit the protective feeder relay to trip the non-auto-reclosing breaker. In this manner we ensure discriminative fault clearance.

Finally, in the third group each feeder breaker is provided with auto-reclosing features. If inverse time overcurrent relays are used, as a rule they are supplemented by instantaneous overcurrent elements.[4] On a transient fault the instantaneous element trips the breaker before a branch fuse blows. After the AR-interval elapses (determined by the setting of the reclosing relay) the breaker recloses. If the fault is persistent, no second chance is given the instantaneous element to operate, but the inverse time relay is used for this purpose to give branch fuses time to blow and so reduce the dislocation of supply to a minimum. Should the breaker not trip within a period set after reclosure, the instantaneous element is prepared for further operations. In the event of a persistent fault on the unfused portion of the O.H.L., the fault will be cleared by the inverse time overcurrent relay.

The circuit diagram for automatic breaker reclosure via solenoid is shown in Fig. 8, assuming sequence selector switch S_1 is moved into auto position A and switch S_2 into neutral position N. At the occurrence of a fault, contact IE-1 of the instantaneous element closes the circuit to the reclosing unit RU, the latter having three contacts. The first contact RU-1 maintains the circuit to relay RU; the second contact RU-2 closes the circuit to the trip coil TC and initiates tripping; while the third contact RU-3 completes the circuit to the timing element T of the reclosing relay RU.

After the AR-interval elapses (the latter being determined by the timed contact T-1) the circuit to the auxiliary relay A is closed. This in turn closes the circuit to the contactor coil C of the solenoid, via contact A-1, consequently initiating the circuit-breaker to reclose automatically. The second contact of relay A, namely A-2, opens the circuit to tripping coil TC, thus preventing a tripping impulse reaching the breaker after it has closed. However, contact A-1 has a second function—that of energizing locking element LK of the RU relay which opens its normally closed contact LK-1 instantaneously, but closes with time delay, the latter being adjustable.

Thus, delay contact LK-1, set, say, for 10 to 15 seconds, remains for this period open, and, should a persistent fault occur, will prevent the instantaneous element from operation, as no tripping impulse will reach the breaker so long as LK-1 is open. However, if the fault persists, the inverse time overcurrent relay will operate within this blocking period (10 to 15sec); contact I-D completes the tripping circuit before the delay contact LK-1 closes, the trip coil becomes energized, the circuit-breaker will trip and remain open, and no second reclosure will take place. After the blocking period has expired the instantaneous element and breaker are ready for further operations. But if, for example, the disc of the inverse time overcurrent relay closes its contact I-D at the instant contact LK-1 closes, a second automatic reclosure is possible.

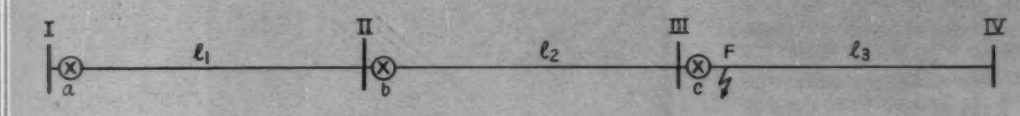


Fig. 7a. Single-line diagram.

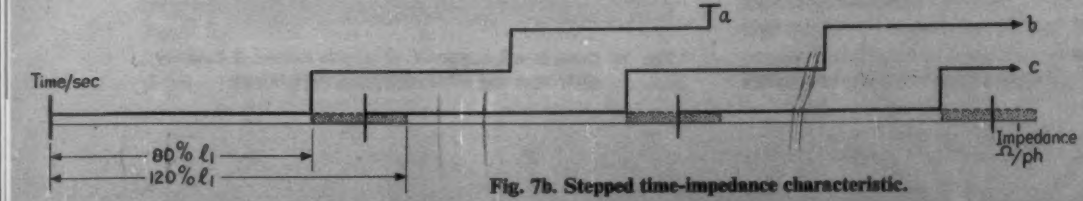


Fig. 7b. Stepped time-impedance characteristic.

Fig. 7. Overlap impedance protection for tail-end feeder.

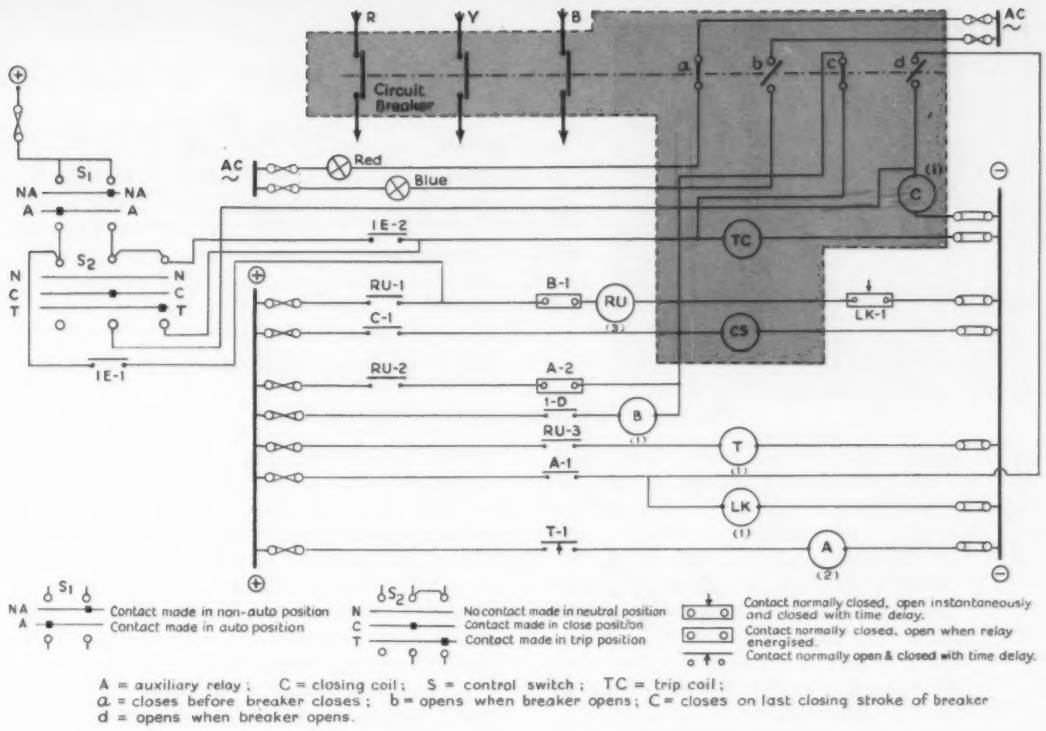


Fig. 8. Control circuit for auto-reclosing circuit-breaker with solenoid-operated mechanism.

It follows that the setting of contact LK-1 is to be related to the setting of the inverse time overcurrent element, assuming minimum generating plant.

This scheme can be extended by locking the circuit-breaker in open position in the event of a persistent fault and resuming operation by closing the breaker manually. This can be achieved by using blocking relay B which, when energized via the disc of the inverse time overcurrent relay, opens the circuit to the reclosing unit RU and remains open until relay B is reset manually. The latter can be omitted if counting devices for automatic reclosing and manual and automatic reclosing are incorporated into the circuit and arrangements are made to lock the breaker in open position by means of the counting device after several auto-operations have been recorded. This will prevent the breaker from being exposed to severe conditions and will enable us to inspect the breaker after a certain number of automatic operations.

Finally, for non-automatic operation, switch S_1 is moved to NA position and S_2 into neutral position N. In the event of a fault, tripping is initiated via the instantaneous element only (contact IE-2 closes the tripping circuit) and reclosing is carried out manually.

2.2. Ring mains and mesh-connected networks

Here auto-reclosing is more complex than for radial networks as two or several circuit-breakers are involved in the event of a fault. For these networks, simultaneous high-speed tripping over the whole length of the feeder is required. Successful high-speed reclosing is ensured if the two ends of a feeder section (see Fig. 9a, fault location F) have been tripped simultaneously, otherwise the fault arc may not have been extinguished should the breaker at the fast end reclose before the breaker at the other end trips. There are two methods of securing simultaneous tripping: (a) expensive intertripping via pilot wires, not considered for economic reasons, and (b) temporary extension of the instantaneous zones, say from 80% to 120% of the line length, by applying overlap impedance protection as outlined earlier.

From inspection of Fig. 9b, it follows that for the ring main shown in Fig. 9a the first or instantaneous zones of the impedance relays are extended into the adjacent feeder sections. Thus at the occurrence of a transient fault (say in section AB, fault location F) both circuit-breakers *a* and *4* will trip and reclose at high speed. For a transient fault F_1, breakers *a*, *b*, and *3* will trip simultaneously with high speed and on reclosure the three breakers remain closed. For a persistent fault F_1, again the three circuit-breakers will trip simultaneously, but only breaker *a* will reclose and stay closed, while breakers *b* and *3* will reclose but trip again and no further reclosure will take place.

This is due to the fact that at the instant of reclosing the first zone setting of relays *a*, *b*, and *3* has been moved back automatically by means of the reclosing relay from 120% to 80% of the corresponding feeder length, causing relay *a* to under-reach while relay *b* trips in its instantaneous zone and relay *3* operates in its second zone. Thus on the second trip, fault F_1 has been cleared discriminately.

The basic circuit for overlap impedance protection

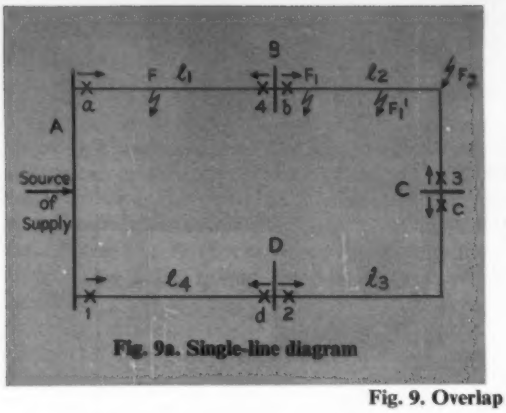


Fig. 9a. Single-line diagram

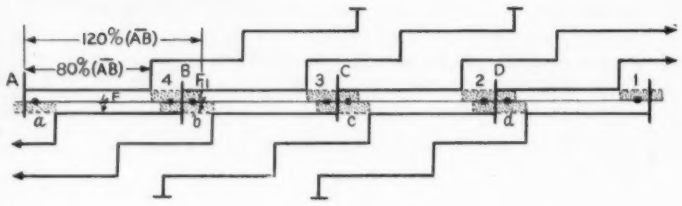


Fig. 9b. Stepped-line impedence relay characteristics.

Fig. 9. Overlap impedance protection for a ring main.

using highly sensitive rectifier type relays, is shown in Fig. 10.[5,6] For clarity's sake the directional element, switching, and self-sealing circuits have been omitted. Operation is initiated by overcurrent starting relays which select simultaneously currents and voltages according to the nature of the fault and apply these quantities to the impedance-measuring element DM. At the same time the former starts the timing unit t, provides via the rectifier a d.c. tripping current, and energizes the reclosing unit RU, thus preparing the latter to operate at the instant the circuit-breaker trips.

It should be noted from Fig. 10 that a high-speed sensitive moving-coil d.c. relay is employed. The rectifiers are connected so that the difference between current v on the voltage or restraining side and current i on the current or operating side flows through the relay. For $v=i$ we have $v/i=1=Z_R$, the ohmic setting of the relay, no current flows through the relay once we have reached the point of balance. For $i>v$ or $Z_R<1$ the operating force is larger than the restraining force, and the relay will initiate tripping. On the other hand if $v>i$ or $Z_R>1$ the restraining force is larger than the operating force, and the relay will restrain. For a fault, say F_1' (see Fig. 9a), timing unit t of relay a will, after the elapse of t_2 seconds, open its contact *t-2* and insert resistance in the potential coil circuit, thus reducing the restraining force of the impedance relay a and causing operation in the second zone, provided relay b is out of action. Similarly, for a remote fault F_2 the relay will operate in the third zone after the elapse of t_3 seconds. This is achieved by inserting an additional resistance in the potential coil circuit, thus reducing again the restraining force.

For a fault, say at location F_1, Fig. 9b, the relays a, b, and *3*, having first zone ohmic settings $[r_1+\{(r_3-r_2)R^1/r_3+r_3+R^1\}]$ (see Fig. 10), close their contacts DM-1, and the timing units t close contacts *t-1* in about 0·1sec, thus completing the circuit to the tripping relays TR which, in turn, close contacts TR-1 and trip breakers a, b, and *3*. At this instant, timed contacts RU-[1] of each reclosing relay RU initiate reclosure of the circuit-breakers a, b, and *3* in about a period equal to the AR-interval. At the instant of reclosing, instantaneous contacts RU-[1] close, adjusting the ohmic settings of the three relays from 120% to 80% of the corresponding line length by short-circuiting resistance R^1. In this manner relay settings are automatically modified. Subsequent to re-

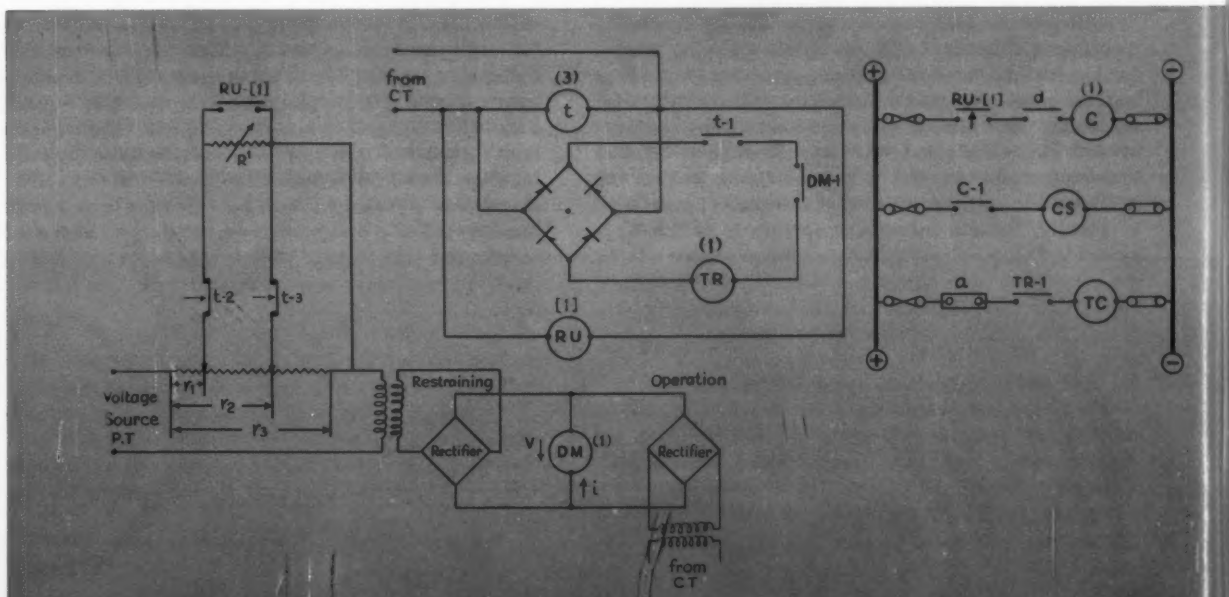


Fig. 10. Basic circuits for control of overlap impedance protection (see Fig. 9a—relay *a*).

closure, a time-delay relay incorporated in the RU unit and set for about 10 to 15sec prevents reclosing for this period should the fault persist. Thus a persistent fault F_1 which is beyond the reach of the impedance relay *a* makes it non-operative, while for relays *b* and *3*, F_1 is within their reach, initiating them to be cleared discriminately, and breakers *b* and *3* will be locked in open position as automatic reclosing is prevented from operation for about 10 to 15sec. Obviously, so long as the breakers remain in open position the RU relays become de-energized and their RU-[1] contacts open, thus restoring the settings from 80% to 120% of the appropriate feeder length. If fault F_1 is of transient nature, no second tripping of relays *b* and *3* occurs and the latter revert to normal operation after the blocking period (10 to 15sec) has expired.

It should be pointed out that if auto-reclosing should take place in the high-speed zone (0·1sec), circuit arrangement has to be made so that automatic reclosing is prevented after the elapse of t_1=0·1sec. At the occurrence of a fault, say at F (see Fig. 9a), and assuming the protective gear *4* fails to operate but reclosing is not restricted to the high-speed zone, auto-reclosing is possible with time-delay in the second or third zone. Obviously, the fault is not cleared simultaneously from both ends, hence relay *a* will trip and reclose and subsequent to its second trip will lock its circuit-breaker in open position. Relay *3*, operating with time delay in its second or third zone, becomes energized, trips breaker *3*, recloses, and remains closed, and converts the network into a tail-end feeder, but no interruption of supply to any substation takes place.

On the other hand if reclosing in the high-speed zone only is adopted, circuit-breaker *3* will trip but not reclose; hence no supply for substation B will be available.

Finally, regarding the magnitude of resistance R^1, the latter must be related to zone 1 (r_1) and zone 2 (r_2) and referred to the impedance range in use. Considering relay *a*, resistance R^1 is determined as follows:

Let $a_1=(80/100)l_1\%$ and $a_2=(120/100)l_1\%$. We have, according to Fig. 10,

$$(a_2/a_1)=\frac{r_1+(r_2-r_1)(R^1)/(r_2-r_1+R^1)}{r_1}$$

$$R^1=\left\{\frac{(r_2-r_1)(a_2/a_1-1)}{r_2-(a_2/a_1)r_1}\right\}r_1$$

For example: r_1=0·4Ω; r_2=0·7Ω; $a_1=80l_1/100\%$; $a_2=120l_1/100\%$. Relay constant=k=6 000Ω

$$R^1=\left\{\frac{(0\cdot7-0\cdot4)(120/80-1)}{0\cdot7-(120/80)0\cdot4}\right\}0\cdot4=0\cdot6\Omega;$$

$$R=kR^1=0\cdot6\times6\,000=3\,600\Omega$$

In a similar manner resistance R^1 can be determined for the remainder of the relays.

Example: Let us determine the time for system disturbance for a fault F_2, shown in Fig. 9a, assuming circuit-breakers *b* and *3* have identical characteristics and the reclosing cycle is as follows (see legend to Fig. 1): t_p=3 cycles; t_{TC}=2 cycles; t_A=3 cycles; t_{AR}=15 cycles;

No. of Cycles	*Time sec*	*Operation*
0	0	Fault occurs
t_p=3·0	0·06	Near-end relays *b* and *3* operate and energize the trip coils
$t_p+t_{TC}+t_A$=8·0	0·16	Near- and far-end breakers trip (total break time ($t_{TC}+t_A$) =5 cycles=0·1sec)
$t_p+t_{TC}+t_A+t_{AR}$=23·0	0·46	Near- and far-end breakers reclose (AR-interval 0·3sec).

Thus the total fault clearing and reclosing period is 23 cycles.

3. Auto-reclosing in interconnected networks[7]

Automatic reclosing in interconnected systems deriving their supply from two or several major power stations differs from that in medium-voltage networks, being fed from one source only. In h-v networks the AR-interval is primarily related to system stability and reconnection of the tie-line must take place before the phase angle between voltages of the disconnected system exceeds the value of safe resynchronization. Subsequent to a transient fault, reconnection of the tie-line has to take place at such a speed that any redistribution of power has no adverse effect on synchronous plant. Thus auto-reclose requirements for interconnected networks are very fast protective relaying, high-speed tripping (minimum break time), and rapid reclosing of circuit-breakers.

In general, air-blast breakers are the most suitable. Circuit interruption takes place in two stages. First is the high-speed separation of spring-closed arcing contacts by a blast of air from an external source followed by a second stage—the opening of a series isolator which in turn, at "fully open" position, cuts off the air supply and the sprung arcing contacts reclose. This action is used to initiate reclosing of the isolator with a minimum AR-interval, long enough to de-ionize the fault path and maintain stability, but short enough for the disturbance to remain unnoticed by the consumers.

As a rule, a larger AR-interval can be tolerated if the systems are not tied via a single circuit but interconnected via several O.H.L., and so long as the re-apportionment of power in the event of a fault does not cause the phase displacement between the alternators of parallel operating stations to drift beyond a permissible value for satisfactory resynchronization on reclosing. For instance, loss of synchronism is likely upon the occurrence of a 3-phase fault with the generating stations being interconnected via duplicated tie-lines. This may

come about as a result of redistribution of power subsequent to fault clearance.

Thus, when dealing with auto-reclose problems, besides the requirement of high-speed tripping and rapid reclosing, we have to take into consideration the design of generating and transmission elements and layout of the network. Since the transmitted power is theoretically proportional to the square of the voltage, and inversely proportional to the reactance of the system, we can improve the stability of the power system by employment of a combination of multiple transmission circuits, low reactance of alternators and transformers, series capacitors, high-speed voltage regulators, and last, but not least, high-speed tripping and rapid-reclosing circuit-breakers.

Another factor influencing the AR-interval is single-pole auto-reclosing for protection against line-to-earth faults in systems with solidly earthed neutral. Here, stability is ensured with increased AR-interval by disconnecting the faulty phase only, and continuity of supply is maintained for a longer period via the healthy phases. However, for extra-high-voltage feeders of considerable length, the capacitive current induced in the disconnected phase is likely to increase the dead time.

It follows that the requirements for automatic reclosing in interconnected networks are:

1. Very fast protective relay operation.
2. Minimum break time of the circuit-breaker.
3. Locking the breaker in open position subsequent to unsuccessful reclosure.
4. For systems with solidly earthed neutral and line-to-earth faults, to reclose a single phase; but for persistent faults to arrange 3-phase tripping and lock the circuit-breaker in open position.

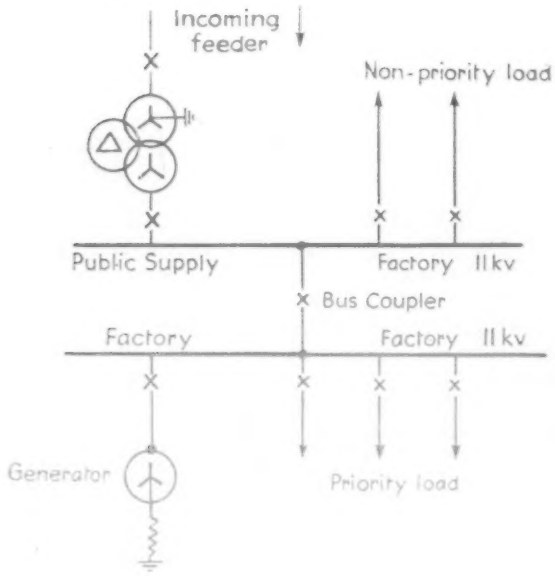


Fig. 11. Single-line diagram of a factory network and public supply system operating in parallel.

Finally, a few notes on automatic reclosing in the case of a large factory supply system which is fed from its own generating plant and interconnected with a public supply system. Here both networks are paralleled via a bus-coupler, as shown in Fig. 11. It is seen that the alternators feed the bus-bars which are connected to the priority industrial load, while the incoming feeder provides the supply for the bus-bars connected to the non-priority factory load.

On the occurrence of a fault on the public supply, the high-speed sectionalizing protection trips the bus-coupler and the non-priority load remains disconnected for a period equal to the AR-interval. There is no need to reclose the bus-coupler automatically, because the rated output of the generators is designed to cope with the priority load. If auto-reclosing of the line circuit-breaker is successful the non-priority load is restored in a fraction of a second and paralleling of both supply systems takes place by manual operation.

Summary

Slow- and high-speed auto-reclosing is applicable to O.H.L. only and is successful when clearing faults of a transient nature. In modern practice it is unthinkable to transmit power without the use of automatically operated circuit-breakers. In medium-voltage ring mains and mesh-connected networks, existing slow-speed breakers and protective relays can be retained and slow-speed auto-reclosing is in some cases justifiable. However, in most of the up-to-date networks high-speed automatically operated circuit-breakers are used.

When applying impedance overlap protection the reclosing time may be reduced considerably. In e-h-v systems the auto-reclosing requirements are: very fast-operating protective relays, high-speed circuit-breaker operation, and reduced dead time. A large AR-interval is tolerable in systems with solidly earthed neutral and single-pole auto-reclosing in the event of line-to-earth faults.

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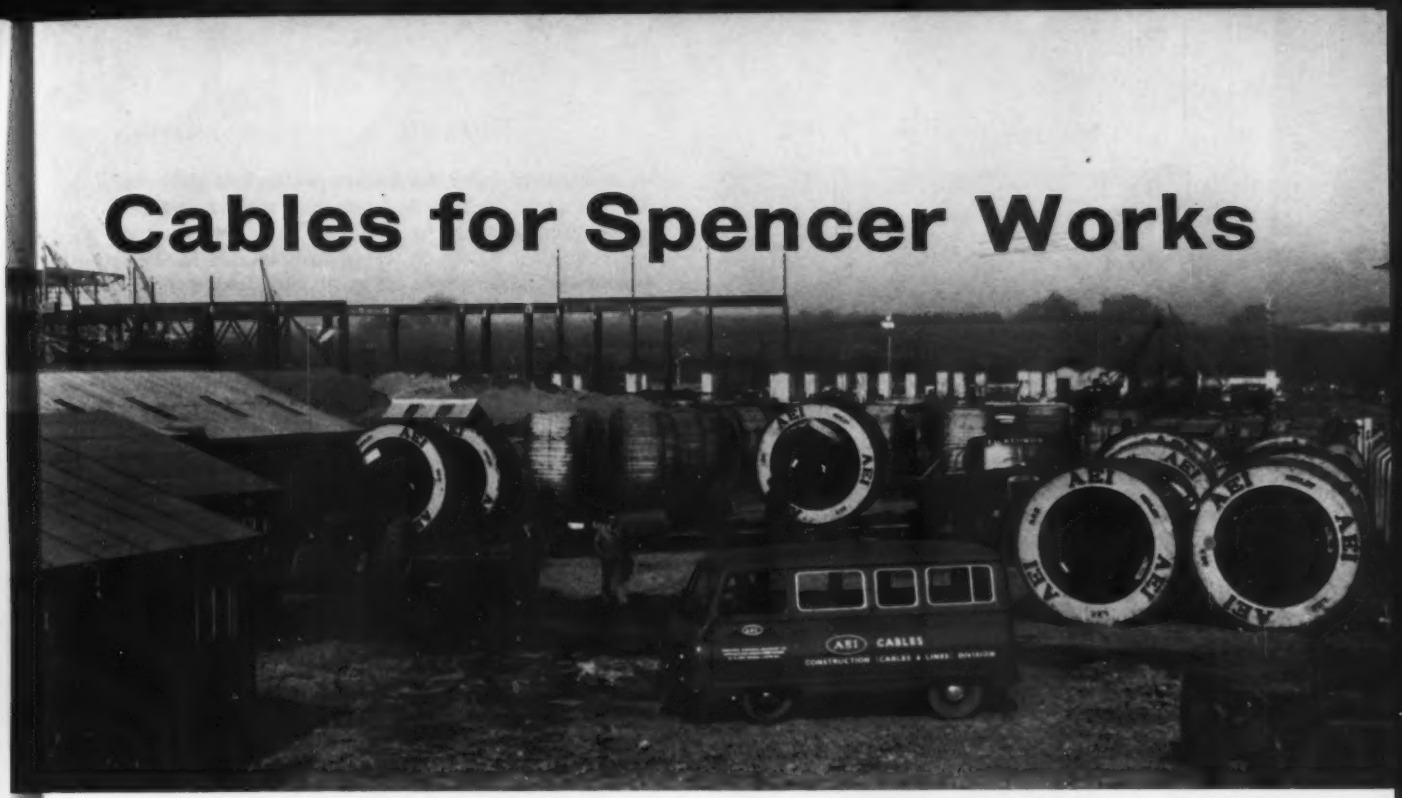
Cables for Spencer Works



AN IMPRESSIVE ARRAY of full cable drums at the site of the new Spencer Works of Richard Thomas and Baldwins as A.E.I. deliver part of their order for this huge steelworks project at Newport, Monmouthshire.

At the time the photograph was taken there were sixty-seven drums in the compound containing 36 000yd of 33kV and 11kV cables. Cabling work is being undertaken by A.E.I. Construction (Cables and Lines) Division under terms of a contract worth £½ million.

Constant construction work has been in progress on the four-mile-long site near Newport for many months. In the background of the photograph can be seen a small part of the structural work in the shape of the steelwork of the Hot Strip Mill.

New British Standards

B.S. 3360:1961—Copper Conductors in Insulated Cables and Cords

B.S. 3361:1961—Copper Conductors in Insulated Cables and Cords (Metric Units)

These two British Standards bring together the requirements for copper conductors at present appearing in many British Standards for electric cables—a step towards simplifying the revision of existing standards. The two specifications are concerned with only the conductor in the finished cable.

In the interests of economical production, more latitude has been given in the make-up of shaped conductors than was permitted in earlier British Standards.

Plain, tinned, annealed, and hard-drawn copper conductors are covered by the specification, but conductors for aircraft cables, telecommunication cables, radio frequency cables, and mineral insulated cables are omitted.

B.S. 3361 is a counterpart in metric units of B.S. 3360, but the metric sizes specified in B.S. 3361 are not direct conversions of those specified in B.S. 3360. *Price* 7*s.* 6*d.*

B.S. 1441:1961—Galvanized Steel Wire for Armouring Submarine Cables

This new edition of B.S. 1441 has been extended to cover four classes of galvanized steel round wire from 0·34in. to 0·083in. diameter for armouring submarine cables.

Classes covered are: mild-steel wire, tensile ranges 24–32ton/sq.in. and 29–36ton/sq.in.; medium-tensile steel wire, tensile range 42–52ton/sq.in.; and high-tensile steel wire in tensile ranges 60–70ton/sq.in., 70–80ton/sq.in., 80–90ton/sq.in., and 95–110ton/sq.in.

Methods of test, test requirements, and tolerances are specified, and details are given relating to the various sizes for each class and tensile range of wire, selection of samples, retests, galvanizing, packing, and identification. *Price* 4*s.* 6*d.*

Copies of these Standards may be obtained from the British Standards Institution, Sales Branch, 2 Park Street, London, W.1. Postage is charged extra to non-subscribers.

SCHOOL for Jointing Skills

AT GRAVESEND, under the shadow of the chalk cliffs near A.E.I.'s cable factory, is a unique "training school" whose graduates are to be found in many countries applying their skills on cable installations of every magnitude and description.

This is the A.E.I. Jointing School.

The Jointing School maintains a constant flow of skilled jointers into the A.E.I. Construction (Cables and Lines) Division's organization. (Prior to the setting up of this Division it was known as Henley's Contract Department Jointing School.) For seventeen years it has not only trained jointers for the Company but has also, when so requested, trained and given refresher courses to jointers in the supply industry at home and overseas.

First Beginnings

The idea from which the Jointing School grew originated from a scheme set up as far back as 1937 by Mr A. V. Burnett, who is now general manager of the Construction Division. An important contract called for a large number of jointers to be made available, and to meet this need he established a training course at the Company's Caledonian Road stores in London. The arrangement proved so valuable that the training scheme became a permanent "school".

This training centre was a ready-made nucleus for development when in 1944, at the Gravesend works of the Company, the suggestion was made of officially indenting apprentice cable jointers. Thus the present-day Jointing School came into being, to be eventually set up on its present site adjacent to the cable works.

The "complete jointer" must be thoroughly familiar with all the materials and processes with which he must work if he is to carry out his job responsibly. The methodical training of skilled jointers requires long-term planning, and the trainees who pass through the school undergo a four-year course. In actual fact the course is so well balanced that the apprentice is fully qualified ten months before the end of his apprenticeship.

But before we go into details of the training given to apprentices, let us have a look at the School itself.

The School

The actual premises of the School are a group of Nissen huts, comprising a main administrative office, a general office, and a workshop and stores section. A well-equipped lecture room is also in use.

The realistic setting of the School's "construction ground" no doubt contributes to the success of the boys who train there. Out of the earth, eight joint bays have been excavated, similar to those to be found on actual contract sites. The bays are permanent and protected from the weather by the ubiquitous jointers' tent. Gaining their first experience in these conditions, the boys feel at home when they eventually go out on a real job.

Five of the joint bays are set aside for low-voltage and medium-voltage work of up to 11kV and the three other bays are maintained exclusively for 33, 66, and 132kV jointing. Besides the jointing bays two poles and a gantry

have been erected for overhead jointing practice on low- and high-voltage cable terminations.

Selection of Future Jointers

The average age of the school-leaver is fifteen and a half and, when accepted as an apprentice, he can look forward to extensive training, followed by a steady, interesting career.

Most of the A.E.I. intake are youngsters straight from school, but application is open to young men already employed in the Company and, indeed, from anyone outside the A.E.I. organization. All who apply are carefully vetted to ascertain their suitability for a jointing career: there is no doubt that the open-air life which such a trade offers is an inducement to the young man who applies for a craft apprenticeship in cable jointing, and there is the additional lure of service overseas which many of them look forward to when opportunity offers.

The desire to become a jointer is not enough in itself, however. Academic accomplishments are secondary to manual dexterity, but the type who makes a successful jointer must be keen as well as practical, willing to rough it out of doors, and be capable of working on his own initiative—in a word, he must be resourceful. The training he undergoes is designed to bring out these qualities.

Up to a dozen boys are accepted each year from amongst the annual group of applicants for apprenticeship. But before the choice of apprentice jointers is made, the group are asked to listen to one of the School's instructors—a man who has experienced the practical side of the jointer's life. He emphasizes, among other things, the ruggedness of the life and the possibility of being called out of bed in the middle of the night to be ready to travel anywhere to repair a cable fault! Anyone who has ideas of a jointer's job being a cushy one is quickly disillusioned.

Those who are chosen as probationary apprentice jointers enrol in a part-time day and evening City and Guilds Electrical Installation course at technical college and undergo six months of preliminary "orientation"—that is, they tour the cable factory and the distribution equipment works, noting how the cables and jointing accessories on which they will be working are fashioned. They also spend part of their time at the Jointing School watching simple joints being made. A series of aptitude tests follows, and it is upon the result of these tests, backed by the personal recommendation of their instructors, that their acceptance as jointer apprentices depends.

On being accepted, the apprentice spends the next eighteen months alternating monthly between the works and the Jointing School. The last fourteen weeks of this period are spent wholly in the School.

During the period spent in the works he is familiarized with all aspects of cable making, distribution equipment manufacture, and assembly.

In the School he is progressively familiarized with all types of joints, terminations, and accessories up to 33kV and will continue his City and Guilds course until he is

▲ Apprentices at the Jointing School get a taste of cable pulling before practice jointing commences.

▲ The ability of the probationer apprentice is judged by work on simple joints.

▲ Progress: 33kV oil-filled cable jointing at a later stage in the course.

eighteen. He will then be considered ready to go out with experienced jointers as a mate on actual contract work.

The suitability of the jointer apprentice for his chosen craft becomes evident as training proceeds but, so well does the initial selection system work, that it can be stated here that only five of its ninety or so trainees have failed to "pass out".

Progressive Training

The Jointing School maintains three main training schedules which are designed to fit a trainee first to act as a jointer's mate and later to become accomplished in all aspects of jointing, including supertension cable work, as his prowess increases. For example, the first schedule, for training as jointers' mates, is put into practice by the boys in their second year. It covers basic instruction on the care of tools and plant, demonstrations of jointing operations, and the actual making of simple joints. Various talks are given to the apprentices on aspects of the jointer's craft, including the all-important subject, repeated in each schedule, of safety precautions.

After this, during his third year, the apprentice is sent to gain further practical experience in the field. After nine months on contract sites, he returns for a two-month course at the School on low-voltage and medium-voltage cable jointing, learning and following instructions. This course is an extensive one, embracing twelve different types of cable terminations to distribution equipment, making off live cable, and five types of 11kV joints and terminations. Lectures on joint and cable design, metals, and insulating materials help to improve the apprentice jointer's background knowledge of his craft.

Now competent in the basic jointing skills, the apprentice can take his place as a mate to fully trained jointers on contract work. During his fourth year he progresses to the third training schedule, back at the School once more, this time on supertension (33kV–132kV) cable-jointing procedure. He learns techniques on the various types of high-voltage joints which will place him higher in the jointer's hierarchy. At the end of this period of training he knows the mysteries of barrier joints, trifurcating joints, sealing ends, and oil-filled joints and terminations in all their complexities. Once again lectures are used to round off his knowledge of joint design, stress control, treatment of insulating materials and compounds, and so forth.

Out on his Own

Having passed out of the School, the ex-apprentice is a capable jointer, considered as a key man in the cable installation work of the Construction Division, fully responsible for top-grade work. There is, nevertheless, still a great deal before him. He will, by working with experienced jointers who have spent years at the game, add to his store of "hints and wrinkles" and his knowledge and practice of his craft, until they become second nature. He will work on all varieties of jobs until his experience embraces extra-high-voltage jointing, when he can consider himself one of the élite of the jointing world. During this time, he will be helping to train lads of a later intake to the Jointing School, and so his training completes full circle. Finally, he may reach the even more responsible position of jointing engineer—the top of his profession.

Jointing Instructions

The years of accumulated cable craft resulting from the School's preoccupation with jointing techniques have not gone unacknowledged.

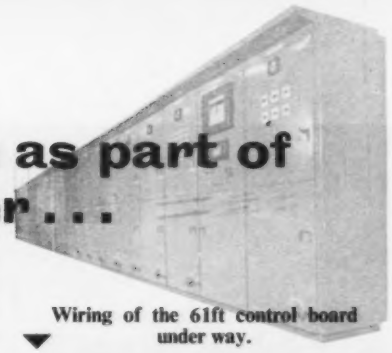
The School's "Jointing Instructions" are models of clarity in step-by-step jointing procedure. Each instruction prepared by the School for making-off or jointing is submitted to the appropriate expert technical panel of the Company for close scrutiny and possible suggestions for amendments.

The School also works in close collaboration with the Research and High-Voltage Laboratories at Gravesend and the greatest possible advantage is taken of any fresh knowledge which might improve cable joints and jointing techniques.

The sum total of all this worrying over attaining perfection is the countrywide acknowledgement of the value of the School. Not only has it ensured that A.E.I. jointers are among the world's best but it has also made its own unique contribution to jointing knowledge.

An instructor lectures a group of apprentice learner jointers in the basic principles of cable jointing.

A.E.I. Cables go to Russia as part of Giant Control Board order . . .



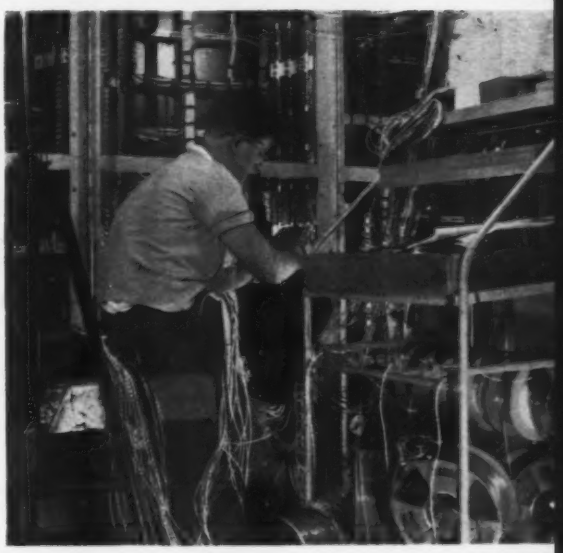
Wiring of the 61ft control board under way.

THE TOP PICTURE shows the largest control board ever to be made in A.E.I.'s Rugby works by the Motor and Control Gear Division. It is 61ft long and includes a 13ft laminated plastic mimic control diagram at its centre which indicates in full colour the various flow paths of materials to be used in a Russian tyre factory at Dneipropetrovsk. It was exported to Russia early this year and is one of fifteen being supplied by A.E.I. to Simon Handling Engineers Ltd, a member of the Rustyfa Consortium which is supplying and installing the complete equipment for the factory.

This giant board will control motors driving plant for the manufacture of rubber pellets from incoming rubber slabs and the transfer of the pellets to the main storage bins. It will also control equipment used for conveying these pellets from the main storage bins to the process bins at each mixing station.

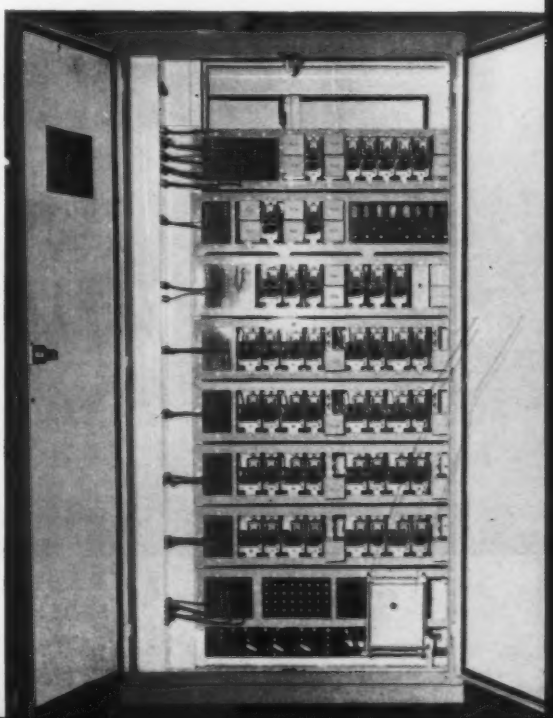
A central control room will contain the 61ft board and others included in the same order—a room which will be the "brains" of the plant, as the factory will be one of the most modern tyre production plants in existence, using automation to the fullest extent.

The second illustration gives a glimpse of the intricate wiring in the same control board pictured above. There is a tremendous amount of work involved in the wiring of this type of equipment, and circuit identification is of prime importance. P.V.C. insulated cables are ideal for the purpose, as this plastic is tough yet flexible and is available in a very wide range of bright colour combinations. More than 120 miles of A.E.I. p.v.c. insulated switchboard control cables will eventually be used in the fifteen control boards supplied to Simon Handling Engineers. Sizes of the cables range from 33/0·004in. to 416/0·018in. conductors.



. . . and in Performance Recorders for the same Project

One of the six equipment cubicles for the monitoring of the Dneipropetrovsk plant.



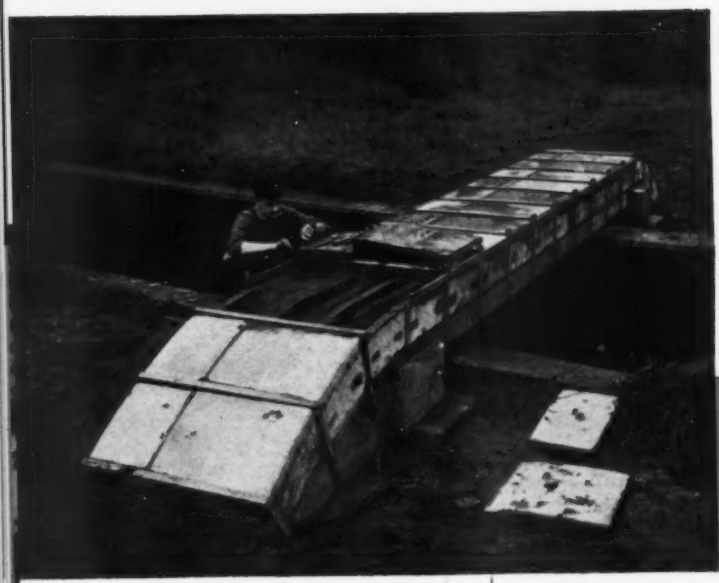
Other equipment used in the Dneipropetrovsk project is also wired with A.E.I. cables. A number of automatic performance recorders, manufactured by the Digital Engineering Company Ltd, of London, are to be installed in the factory.

These performance recorders will be used to monitor the giant tyre plant, transmitting production data from many points in the factory to a central recording office—hence their name of CROWD (Central Recording of Works Data). They will record production figures for every phase of the manufacturing process, from the batches of raw rubber to the cured and uncured tyres.

Besides the recording operation the recorders summarize the operations of the machines and produce a condensed record for analysis.

Six recorders have been supplied for the Rustyfa contract by Digital Engineering, the largest recorder being responsible for 404 tyre press machines. This equipment provides another complicated wiring job, for which colour-coded A.E.I. equipment wires were used—about 10 000yd of solid and stranded types being installed on the Russian order by the manufacturers.

Large A.E.I. Cables at Leeds and Willenhall



TWO IMPORTANT A.E.I. contracts are nearing completion in which large 132kV oil-filled cables play a big part.

Yorkshire

One of these contracts is concerned with the reinforcement of the power supply to Leeds. Power generated at Skelton Grange "B" power station is transmitted to the C.E.G.B. Yorkshire Division's new bulk supply point at Beeston Royds and A.E.I. cables provide the next link in this scheme by a connection from Beeston Royds to Kirkstall power station—a distance of about three miles.

A.E.I. Construction Division engineers have installed two 132kV 0·4sq.in. 3-core oil-filled feeders between Beeston Royds and Kirkstall, the cable size being increased to 0·45sq.in. at various places where it is protected by ducts. The ducted lengths, positioned at main-road crossings and at an under-track crossing of a railway, amount to almost a quarter of the total route length.

The three cores of each oil-filled cable were divided at each end of their run by means of trifurcating boxes, and the individually lead sheathed cores were taken to outdoor vertical type sealing ends on substation structures.

The cable route lay chiefly through streets in the suburbs of Leeds, but two interesting crossings which occurred were dealt with by means of specially constructed cable bridges. The smaller of these was the crossing of Wortley Beck, a 12ft stream which at the point of crossing was embanked by brick retaining walls. For this situation a strap and girder bridge was designed to contain each feeder and its auxiliaries in a separate trough, the troughs being sand filled and protected overall with reinforced concrete sections.

The second crossing was that of the Leeds and Liverpool Canal, which required a rather more elaborate structure, to provide headroom for small vessels using the waterway. This cable bridge, erected close to an existing stone bridge, was fabricated of galvanized steel angle and galvanized sheet steel to form a completely enclosed

Top: illustration shows one of the large joint bays on the Beeston Royds-Kirkstall cabling. The jointers are cleaning up the core chamfers.

◀ *Left:* completing the cable bridge over Wortley Beck. The sand-filled troughs are visible in the open section.

structure. Designed by E. C. & J. Keay of Solihull, Warwickshire, it was sturdily constructed to withstand the strains to which it was subjected while the heavy cables were being hauled over it during installation—an operation which needed considerable effort on the part of the cable-laying gang.

About 31 000yd of auxiliary cables were laid with the feeders over the same route. These comprised two 19-core 7/·029in. PILCSWA and served pilot cables, two 4-pair and one 27-pair 1/·044in. polythene-insulated, PVC SWA PVC telephone cables, and one 4-pair cable of similar construction for low-oil-pressure indication which was laid along approximately 75% of the route.

As might be expected, very large jointing bays had to be excavated for the jointing of these big cables and their accompanying auxiliaries. The illustration shows one of these bays while work was in progress.

Staffordshire

Still larger cables with 0·5sq.in. and 0·6sq.in. conductors have been installed by the A.E.I. Construction Division in the Midlands for the C.E.G.B. Midlands Division, where busbar interconnectors and four 132kV oil-filled cables were required to connect overhead line circuits to the 132kV substation at Willenhall, in the Birmingham area.

The terminating towers of the 132kV grid lines carrying the Ironbridge, Bushbury, Wolverhampton, and Stafford circuits are situated about a mile and a quarter from the Willenhall substation. For the connections, 0·5sq.in. 3-core cables of normal oil-filled construction were installed. At the terminal towers a trifurcating box mounted vertically on the structure divides the three cores of each cable. The cores were individually sheathed on site and terminated on outdoor type sealing ends which were bolted to sealing and platforms designed as part of the tower structure.

Terminating cables in sealing ends on towers normally presents no problems to the jointers, who are protected from the weather by a tarpaulin-sheeted structure of scaffolding fixed to the tower. But at Willenhall they encountered high winds and driving rain in a vicious combination which played havoc with their shelters. They were forced to press on with the work under most uncomfortable conditions.

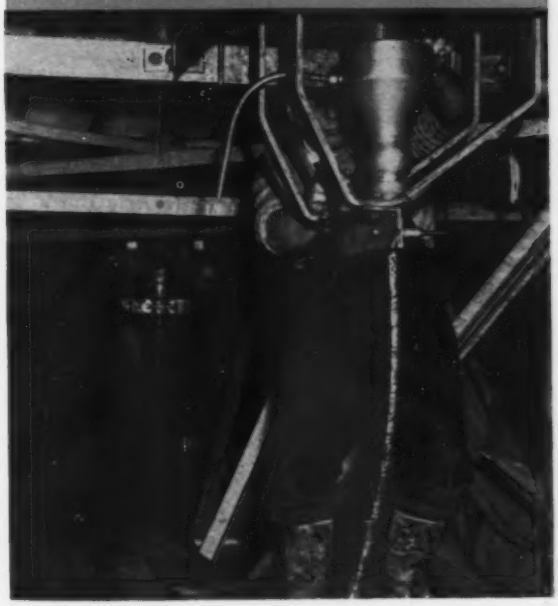
At Willenhall substation horizontal underground trifurcating boxes were used to separate the cores, and the sealing ends in which the cores were terminated were mounted on R.S.J. structures.

For the busbar interconnectors a total of 2 500yd of 0·6sq.in. 132kV single-core 8mm central oil duct segmental conductor, paper-insulated, lead sheathed and reinforced oil-filled cable with anti-corrosion finish was used. Each of the two single-point bonded circuits called for two cables per phase and each cable was laid direct into the ground and terminated in sealing ends.

Acknowledgements are made to the C.E.G.B. Yorkshire and Midlands Divisions for permission to publish details of these contracts.

▲ A.E.I. jointers at Willenhall worked at sealing end terminations protected by tarpaulin shelters on the towers.

▼ Inside the shelter: plumbing a sealing end gland.



? PROBLEM CIRCLE

January Overseas Competition

Our anticipation of a good overseas response to the reintroduced Problem Circle was certainly fulfilled, in spite of the fact that our journal reaches many countries with but a few days to spare before entries must be mailed. We shall try to improve this position in the future as obviously many overseas entries are submitted under a handicap in this respect.

About a quarter of you solved Problem No. 1 correctly, and most solved the milkmaid problem. One ingenious reader, Mr W. J. Bull, resident in Kampala, Uganda, gave the milkmaid an unspecified pencil and dispensed with the 9-measure jug altogether! By filling the 7-measure jug and pouring it into one customer's pail, refilling the 7-measure jug, marking the level of the two remaining measures in the 16-measure container, pouring the latter into the second customer's pail. . . Well, it is easy to work out the rest of the procedure, provided that the pencil mark stays put. Mr Bull, thus outside the pale(!), did the necessary sharing out in eleven moves.

Prizewinners who are being sent £1 10s. are:

Problem No. 1—Mr A. K. Ghosh, c/o Indian Cable Co. Ltd, Jamshedpur 3, Bihar, India.

Problem No. 2—Mr F. Liceni, Fleming 2200, Martinez, Buenos Aires, Argentina.

March Problems

The March problems proved to be very popular, about half of our friends having sufficient versatility to send in solutions to both problems, many of them correct in both cases. Some solutions are extremely meritorious, and it is often a matter of regret that only one prize is available for each problem. Judging from remarks accompanying your entries, all of which are read with enjoyment, the problems offered are the source of spare-time pleasure to a large number of readers.

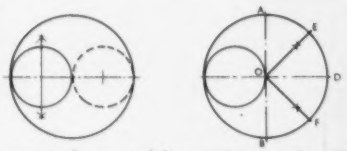
Problem No. 3 seems to have deterred some readers because of its geometrical aspect. We say "aspect", as the construction asked for merely requires the use of a pair of compasses for three simple operations—finding the radius of the small circle, marking off a second radius, and drawing another small circle.

It is obvious that if the small circle is half the radius of the larger then its area is one-quarter of the larger. Place another similar circle inside the larger in such a way as to divide the remaining area of the latter, and we have a solution. Diagram 1 makes this clear.

Problem No. 3

Left: **Diagram 1**

Right: **Diagram 2**



Another solution turned up, without the merit of extreme simplicity offered by the previous answer: this is illustrated by Diagram 2. If angles AOD and BOD are bisected then EOF is one-quarter of the larger circle and the remaining areas, being equal, are also as required.

Lucky prizewinner for this problem submitted the Diagram 1 solution. He is **Mr P. K. Wade, 19 Lawn Road, London, N.W.3.**

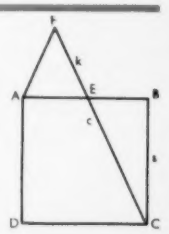
The £1 10s. for the word sum, **Problem No. 4,** goes to **Miss V. C. Dawkins, International Aeradio Ltd, Engineering Division, Hayes Road, Southall, Middx.** The solution is as follows: O, AM, ALL, MAIL, TOAST, LAMMAS, TRAITOR, IMITATOR, ARTHRITIS, IMMORTALS, and the word representing the total is LOGARITHMS.

May Problems

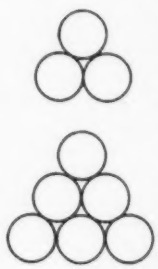
Problem No. 5

In the diagram:
ABCD is a square of side s
AFE is an isosceles triangle
$AF = FE = k$; $FC = c$

Problem:
Find k in terms of s and c



Problem No. 6



Twelve counters can be arranged to form two separate series of triangles—one series being of four triangles each of three counters, the other giving two triangles each of six counters, as shown. Each series uses all twelve counters and all the counters in each triangle touch.

What is the least number of counters required to form six different series of triangles in the same manner, all the counters being used in each series and all, in addition, being used to make one large triangle?

Competitors — Please note new address

Solutions to Problem Circle

Solutions to the Problems 5 and 6 should be sent to the Editor, ELECTRICAL DISTRIBUTION, Crown House, Aldwych, London, W.C.2. Envelopes should be marked "Problem Circle". *Closing Dates:* 20 June 1961 for competitors resident in Great Britain, Northern Ireland, and Eire. For overseas competitors the *mailing date* specified is 20 July.